

ORIGINAL CONTAINS

COLOR ILLUSTRATIONS

Abstract

This is a multicomponent, multidisciplinary project whose overall objective is to build an integrated database, simulation, visualization and optimization system for the proposed oxygen manufacturing plant on Mars. Specifically, the system allows users to enter physical description, engineering and connectivity data through a uniform, user-friendly interface and stores the data in formats compatible with other software also developed as part of this project. These latter components include programs to simulate the behavior of various parts of the plant in Martian conditions; an animation program which, in different modes, provides visual feedback to designers and researchers about the location of and temperature distribution among components as well as heat, mass and data flow through the plant as it operates in different disturbance conditions; a control program to investigate the stability and response of the system under different disturbance conditions; and an optimization program to maximize or minimize various criteria as the system evolves into its final design. All components of the system are interconnected so that changes entered through one component are reflected in the others.

Introduction

The design of complex mechanical systems which are required to operate reliably and autonomously in alien environments is an intricate and iterative process which requires extensive testing in a wide range of hypothetical scenarios. Given the impossibility or the high cost of recreating alien environments on earth, such scenarios have to be generated by computers and applied to simulated versions of the actual mechanical systems. As a result, computer simulation has become an essential and integral part of designing and building mechanical systems to be used in space or extraterrestrial environments.

This specific project was initiated with the aim of providing the essential simulation capability for the oxygen manufacturing plant that the Space Engineering Research Center at the University of Arizona has undertaken to build on Mars. Because of the multidisciplinary nature of the plant's design process, this integrated software project was designed to provide data storage, classification, access and visualization services for all the different groups working on the design and testing of the plant. This project consists of the following principal components

- i) A relational bill of components database;
- ii) A visualization system for animation of the plant's dynamics;
- iii) A control design system associated with data collection equipment connected to an experimental setup;
- iv) An optimization system to maximize specified performance criteria while meeting weight, thermal, cost and other constraints.

The technical features and current status of these principal components are briefly outlined below.

Relational Bill of Components Database

The purpose of this component of the project is to construct a uniform data entry system which can act as a server of information to other components of the project in the appropriate format after conducting basic checks against physical constraints. In addition, the system serves as a rudimentary expert system which can monitor spatial, thermal, electrical and data compatibilities among different system components. Ultimately, this database will act as the common user

interface for entering every piece of information about the system as the system evolves into its final design.

The FoxPro 1.02 database package has been selected to serve as the basic platform for building the desired relational database system. This package was selected principally because of its sophisticated multiple-window and pull-down menu user interface which can permit users from any background to operate the system with ease. The package was used to design a customized data entry and organization system which is specific to the needs of the overall project. The primary objectives of this design was to build a standard, portable database structure, to provide a uniform graphical user interface and to facilitate data access from other software components in the project.

The basic philosophy underlying the design of the database system is to represent the various components in the plant in terms of their connections to each other rather than their own features and properties. This was accomplished by abstracting each of the components into their various input-output characteristics and representing those characteristics in database entities corresponding to connections. This model of the system is depicted by Fig. 1. where a component *A* is connected to component *B* by a set of connections each of which represents an input-output relationship between *A* and *B*. For example, if *A* is a pump and *B* is a heat exchanger, one connection may represent the mass flow from *A* into *B* (with corresponding inlet and outlet pressures) and another one may be the heat flow from *A* to *B* (with corresponding inlet and outlet temperatures). Consequently, a pipe between *A* and *B* can be abstracted into two different connections: a mass-flow connection and a heat-flow connection. In this abstract model, space is also represented as a connection so that intervening volumes of space connect one component to another (with corresponding spatial coordinates on each sides). A space and thermal connection is assumed (and represented by appropriate connections) to exist between every pair of components in the system.

Each component of the plant and each appropriate connection of each component are entered on data forms which are predesigned with appropriate data fields for each common type of component that is used in the plant (e. g. pump, heat exchanger, thermal, mass-flow, etc.). Sample component and connection data forms are shown in Fig. 2. Both component and connection data forms incorporate data fields which are common to all components and connections as well as fields which are specific to certain types of components and connections. Generic forms have been designed so that users can design new forms for components and connections for which forms have not yet been designed. In addition, users can add data fields to existing predesigned forms if that data is needed for a new software package that is being developed for the overall project.

Once all the components in the plant together with their connections are entered into the database, a program written in the FoxPro database language (compatible with other common database languages such as dBase IV) carries out basic compatibility checks between each pair of components that are connected to each other. Since each component is connected by at least space and thermal connections to each other component in the system, this compatibility check includes physical interference and high and low-temperature proximity checks. Warnings are issued to the user in the event any of the compatibility checks fail. This is an essential function for an iterative design process in which a plant component is typically replaced by another model because of a specific improved feature, but the replacement results in changes in a complete array of characteristics associated with the component and its connections (e. g. a pump may be replaced with one that has better power efficiency but the new pump's outlet pressure may not be compatible with the inlet pressure specifications of the existing heat exchanger). A schematic flow-chart of the operation of the database system is shown in Fig. 3.

The database system has the capability to write the entered data in a format that is usable by the other components of this project. Over the coming months, this capability will be enhanced to generate all the necessary files for the other software components of the project. In addition, the

database software will be modified to accept input generated by changes made in other programs of the integrated system.

Visualization/Animation System

The purpose of this component of the project is to construct an animation and visualization system which can serve both as a design tool (especially for packaging) and a communication tool to convey the status of the plant design to researchers and students working on the overall project. With appropriate hardware, this component may ultimately serve as an interactive graphical user interface for controlling different parts of the plant while it is being tested on earth and a troubleshooting system with "what-if" features when the plant is operational.

In this component of the project, each component of the Martian oxygen manufacturing plant is represented as a geometric object of the appropriate shape and size. These objects are constructed in three dimensions using flat polygons. Each polygon, its color, fill, edge and opaqueness attributes as well as its connectivities to other polygons are entered in a data file. This data file (which will ultimately be generated by the relational database program outlined in the previous section) is then read by GAAP (Graphical Analysis and Animation Program), an in-house package developed at the Computer Aided Engineering Laboratory of the Department of Aerospace and Mechanical Engineering, which can draw and manipulate the objects on the screen. GAAP can be used to program the motion of different objects on the screen as well as the perspective of the viewer by varying "camera" angle and location. Figures 4 and 5 show two snapshots of animation sequence depicting the landing and operation of the oxygen manufacturing plant on Mars. These two images were created in the initial stage of the project on a Silicon Graphics IRIS 3130 using GAAP.

Figures 6 and 7 show the same plant in greater detail and with better texture. These images were created on a Silicon Graphics IRIS 4D using Wavefront, a commercial graphics package. This newer system offers substantially better performance features and capabilities and is expected to be the hardware/software platform for the final version of the animation and visualization system for the Martian oxygen manufacturing plant.

Over the next year, the animation and visualization package will be enhanced so that any changes made from the relational database will be instantly reflected in the images generated by this package and any changes in the position of an object, affected interactively with a pointing device through the animation program, will be reflected in the database. Such a capability would be invaluable for designing and packaging the plant.

Control/Data Collection System

The purpose of this component of the project is to construct a control design and data collection system to investigate the stability, sensitivity and response of the plant system to external disturbances and changes in operating parameters. Progress on this component of the project was limited due to unexpected cuts in funding and subsequent departure of personnel assigned to this task.

Over the next year, this component will be developed to perform data collection and basic control functions and to interact with the relational database and animation and visualization software.

Optimization System

The purpose of this component of the project is to maximize or minimize various design and performance criteria subject to physical and cost constraints. This component has not yet been started. Subject to funding levels, this component will be started over the next year with the initial aim of optimizing the placement of different components of the plant inside a constrained space. The program to be developed will interact with both the animation/visualization and the relational database packages for its input and output.

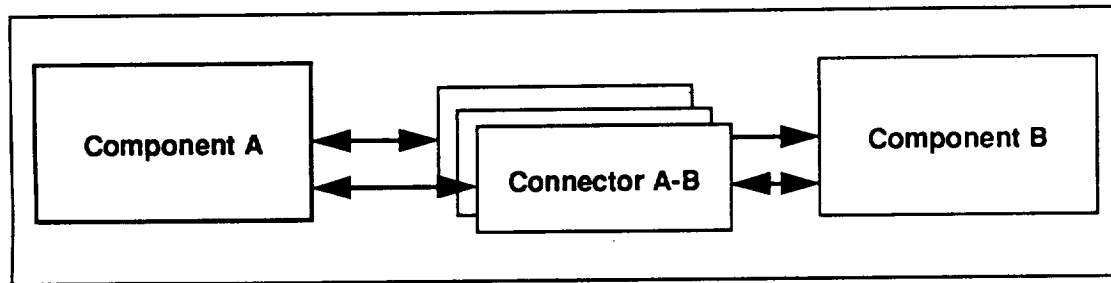


Figure 1. Layered representation of connections

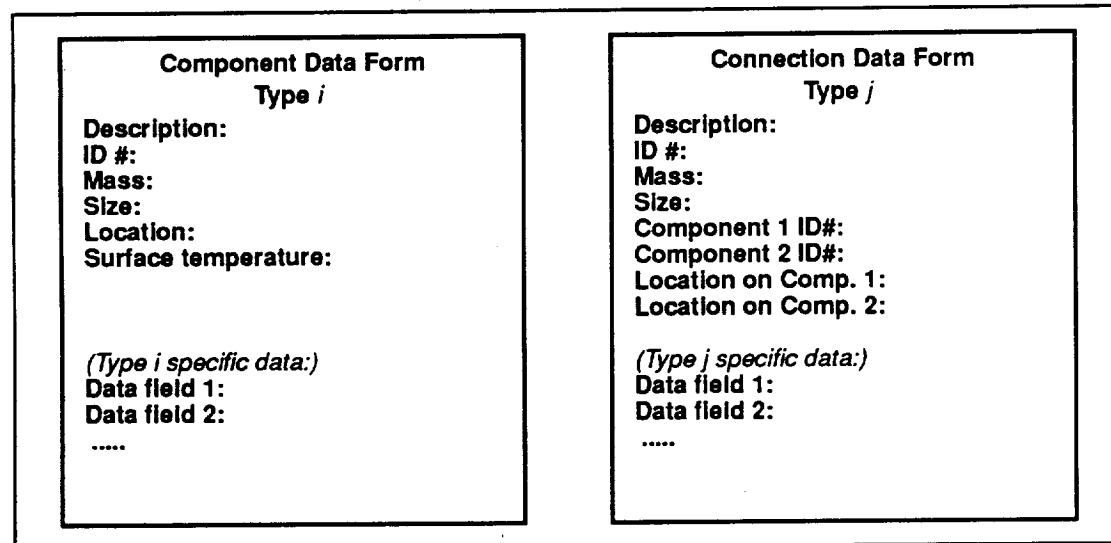


Figure 2. Sample data forms for components and connections

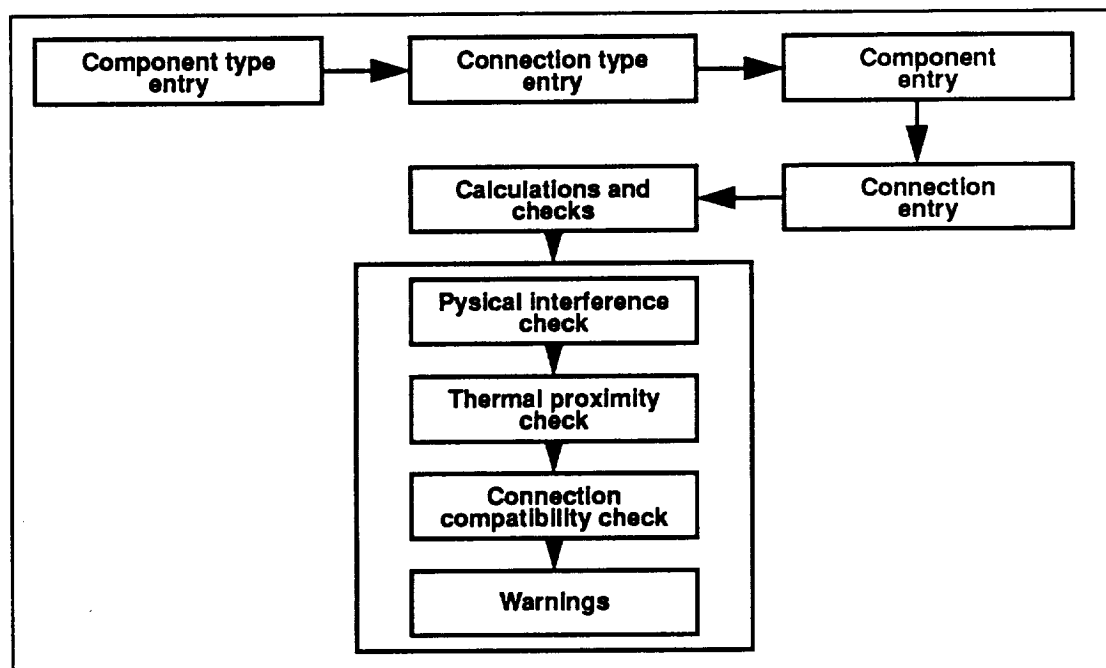


Figure 3. Schematic of database functions

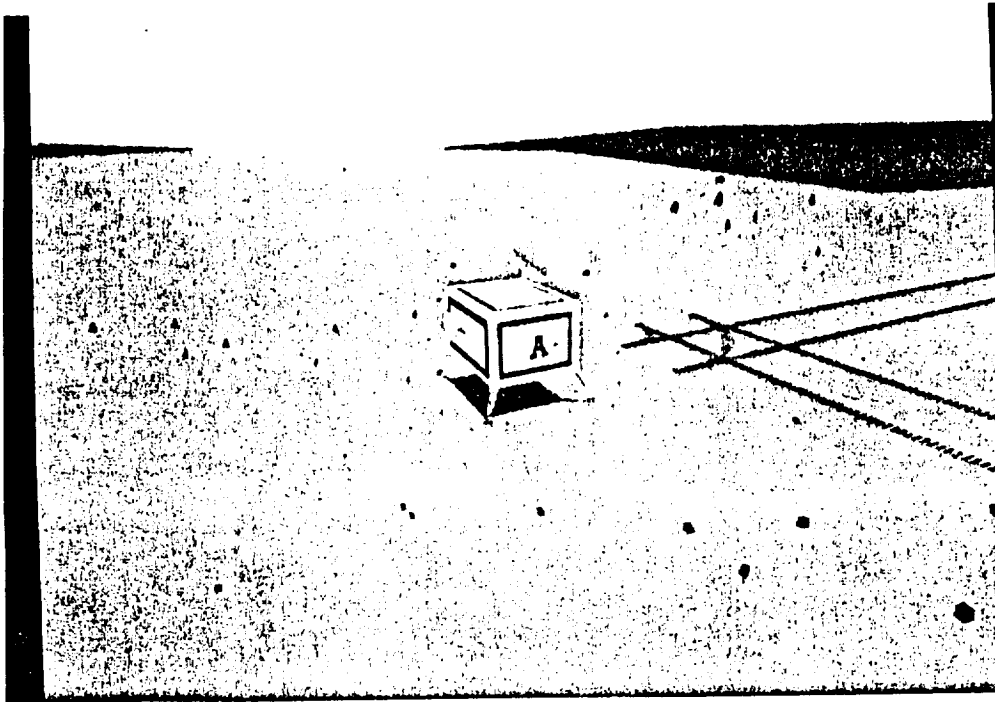


Figure 4. Oxygen manufacturing plant after landing on Martian surface.

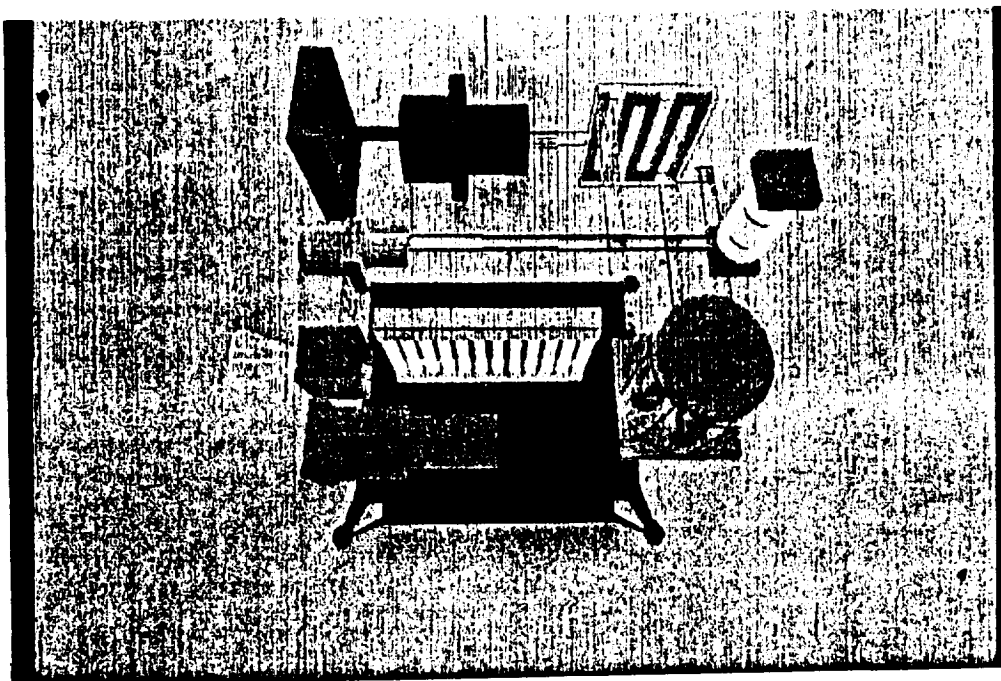


Figure 5. Exploded view of the oxygen manufacturing plant.

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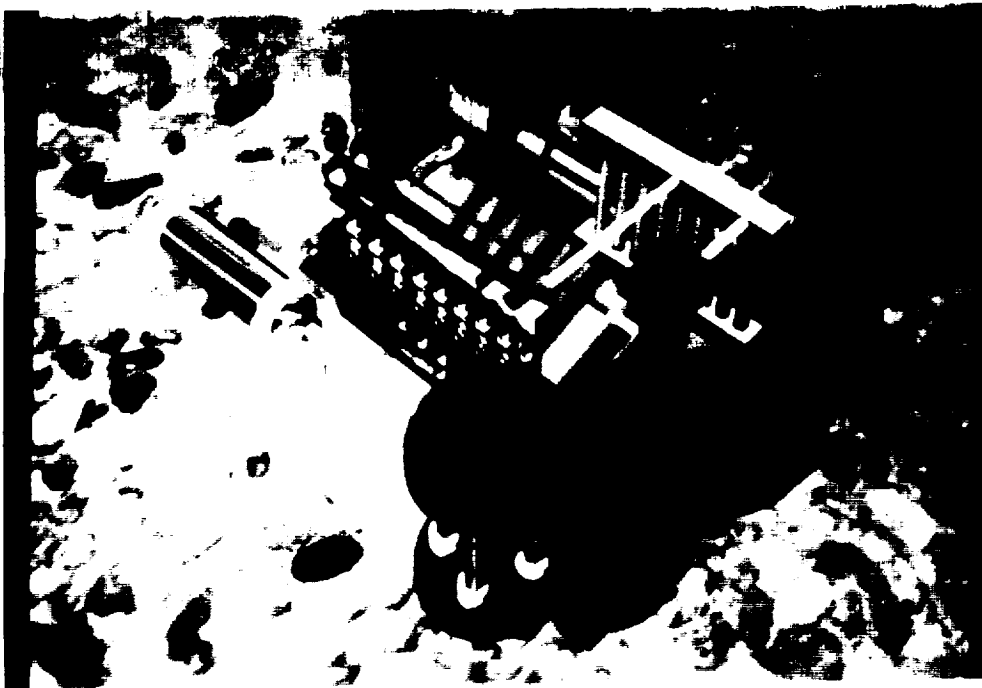


Figure 6. Oxygen manufacturing plant with shading and texture (Earth sunlight).

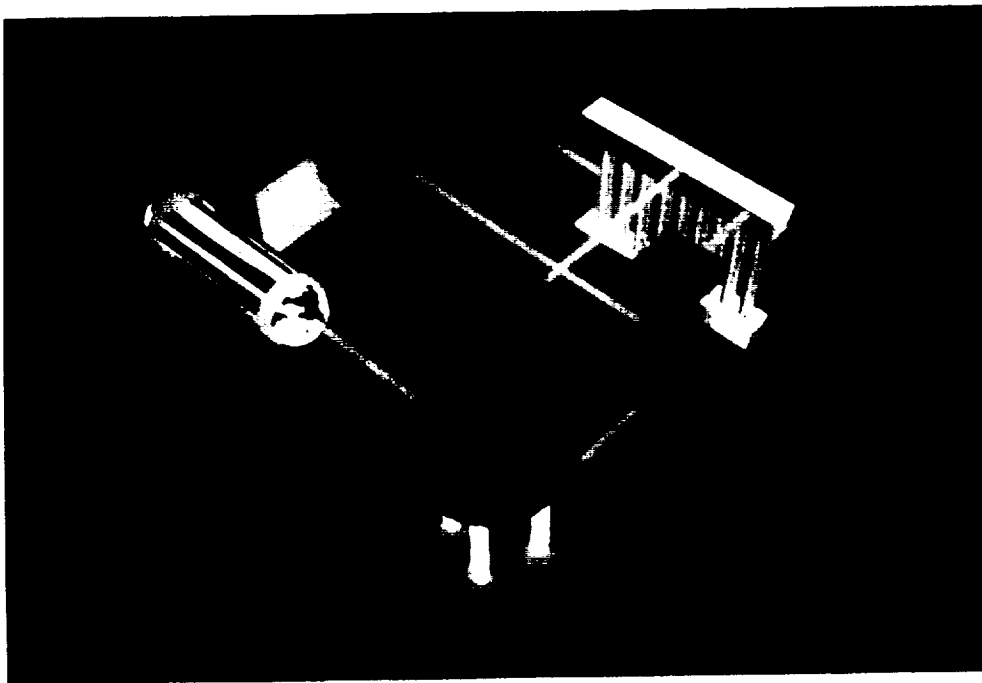


Figure 7. Oxygen manufacturing plant with shading and texture (Martian sunlight).

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